2. Broadband Access Technologies

  BLEN providers are deploying a number of access technologies; more are likely to appear in the not-to-distant future. Candidate technologies include:

- A family of broadband-enhanced copper wire technologies referred to collectively as xDSL, where DSL means Digital Subscriber Line, and the "x" indicates one of the members of the family of DSL technologies;
- Telephone company "fiber to the curb" ("FTTC") or "fiber to the home" ("FTTH") systems, which, as the name implies, extend fiber from the CO to a point either close to individual premises and serving a small number of premises (FTTC), or at the individual premises (FTTH), with coaxial cable or, possibly, copper wires extending into the premises;
- Conventional fiber rings, as deployed by the former CAPs; and
- Broadband wireless systems, such as those associated with the Multichannel, Multipoint Distribution System ("MMDS") and Local Multipoint Distribution Service ("LMDS").

Irrespective of the technology used, an access system generally includes a device at the subscriber's premises that terminates the broadband access link with functions such as signal processing and multiplexing; the physical interface between the BLEN transmission medium and the premises transmission medium, which we will refer to as the Network Interface Device ("NID") in keeping with the terminology used in the PSTN;[104] the transmission medium, and transmission electronics located in the CO.

  While all of the technologies named above may play a role in the BLEN over time, the candidate technology that has the most potential for ubiquitous deployment of broadband services, particularly in the residential and small-business marketplace, is the xDSL family. The FCC has appropriately focused its various proposals and questions in

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[104] The NID may be integrated into the terminal, but since it is today a separate device in the PSTN, and since it also includes protects premises equipment against voltage surges due to lightning strikes and other external events, it is likely to remain a separate device for at least the near future.

the Order/NPRM on this technology. Section E of the Appendix presents a detailed

discussion of xDSL technologies.

3.   Broadband Switching

Consistent with the definition of the BLEN as supporting switched broadband

services, the BLEN includes a switch that is capable of switching broadband signals,

which we have defined as signals whose bit rates are at least 256 kbps. The switch

cannot be a conventional voice switch, because those switch narrowband 64 kbps

circuits.[105] All of the following, however, are candidates for the broadband switch:

- Internet router
- Frame relay switch
- Asynchronous Transfer Mode (ATM) switch
- Fast circuit switch (future possibility)

Inherent in this list are three key distinctions. The first is the distinction between a circuit

switch and a packet switch. In rough terms, when a caller initiates a call, circuit switches

establish a path through the switches and transmission facilities of the network that is

dedicated to that call for its duration. Virtually all the processing in the network is done

when the call is being established and when it is being terminated; in between, the

network has little to do except monitor the connection to determine when one of the

parties has hung up. On the other hand, the network's resources are not used very

efficiently for many calls, for two reasons. First, the resources are dedicated to a call

even if there are long periods of inactivity during which no information is being

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[105] It should be noted that some voice switch vendors are beginning to offer broadband adjuncts that, while plug-in modules for the voice switch, actually switch information in the broadband range we have defined. We do not mean to exclude those developments, but consider the adjunct, not the basic voice switch, to be the broadband element of interest.

transferred. Second, for short-duration calls, the "overhead" time required to establish and terminate the connection may be much greater than the duration of the call itself.

By contrast, in packet switching, information to be transferred is organized into small units, or "packets," each of which has enough information in a packet "header" to inform the network of its destination. The network routes each packet based on this information. Unlike circuit switching, it does not dedicate switch and transmission resources to a particular connection, between two points; instead, it interleaves packets from many different connections.[106] In this way, it makes more efficient use of the network's resources, particularly transmission capacity, but does so at the expense of more processing than that associated with a circuit switch network. In recent years, many of the functions performed by a packet switch have been implemented in hardware, rather than software, allowing the switch to process many more packets per second. The term "fast packet switch" has been applied to switches using this technology.

The second distinction, within packet switching, is between a switch and a router. A switch sends all packets with the same destination along the same path, based on the information contained in fixed tables in its memory. A router may send packets with the same destination along different paths, based on the information contained in dynamic tables that change periodically based on the current status of the network. The distinction between switches and routers is fading as time passes.

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[106] In fact, in one important form of packet switching referred to as "connectionless" communications, which, incidentally, is the form of packet switching utilized by the Internet Protocol, there is no connection at all. Devices send out packets (often called "datagrams") on an individual basis, each of which is independently routed to its destination. A rough analogy is the postal system, which handles each piece of mail individually, with no knowledge of whether or not it is part of an ongoing correspondence between the sender and recipient.

Finally, there is a distinction in the nature of the data units employed by different types of packet switches. Generally, there are two classes of such data units. The first, called frames, are of varying length, with a maximum length that is often thousands of bytes. The second, called cells, are of fixed length and very short – 53 bytes, in the case of ATM. The terms "packet" and "packet switching" are generally used as generic terms that cover both kinds of possible data structures; however, some authors would claim that a packet more specifically refers to a data unit of varying length, and hence equivalent to a frame. To such authors, then, there is a distinction between packet switching and cell switching. We have opted for the more generic use of the term "packet" and "packet switching."

Given these three distinctions, the internet protocol ("IP") involves packet switching that routes frames (with the special designation "datagram"); frame relay involves packet switching that switches frames; and ATM involves cell switching.

There is today a considerable difference of opinion as to whether the internet router or ATM switch is the better choice for BLEN. ILECs generally favor, and are currently deploying, ATM, claiming it has more flexibility to handle different applications. A number of CLECs and ISPs, on the other hand, hold that the internet router is perfectly adequate to handle the applications they plan to support, and that ATM includes an unnecessary amount of processing complexity and extra byte overhead. These characteristics of ATM are caused by its very small data structure, called a cell, that adds at least five bytes of overhead for every 48 bytes of payload (useful information transmitted).

4.   Broadband Interoffice Transport

The interoffice transport portion of the BLEN will use the same broadband facilities as those already in place for the PSTN. These are largely based on SONET transmission over fiber optics cables configured as rings. For the PSTN, the signals are organized into 64 kbps but streams appropriate for voice communications. When used for broadband services, the organization will be organized into circuits with much higher bit rates.

The same choices exist for the addition of such broadband circuits to existing PSTN interoffice facilities as exist in the case of fiber optics DLC systems: 1) use separate electronics transmitting over separate fiber strands in the same cable; 2) transmit over the same fibers, but at different wave lengths, using WDM to derive the additional signals; or 3) use the same bit stream as the PSTN does, with the terminal equipment appropriately upgraded to support the higher bit rates required. Whatever the choice, existing SONET-based management systems will be augmented to support the operation of the broadband facilities.

The ring configuration, already being deployed for PSTN interoffice facilities, has the desirable characteristic that there are two paths between any two points on the ring, corresponding to the two directions one can traverse the ring between the points. Thus rings provide redundancy that allows the network to recover from failures such as the fiber cable being cut. In such ring systems, transmitters literally transmit in both directions around the ring, and receivers monitor both directions of transmission to determine and use whichever has the better transmission quality. In the event one

direction fails completely, or degrades in quality, the receivers will automatically switch

to the other direction, while using some of the SONET overhead to alert a management

system that it has detected a problem.[107] Such SONET-based management systems also

provide other operations functions, such as circuit provisioning and rearrangements,

routine monitoring of continuity and quality, other failure recovery mechanisms, and the

collection of traffic and utilization statistics.

E.   xDSL Access Technologies

1.   Introduction

The available bandwidth in a typical (unloaded) two-wire copper subscriber loop

is considerably greater than that required for voiceband switched telephony. Techniques

for exploiting this "excess" bandwidth for transmitting digital signals to and from

telephone subscribers over existing loop plant have been studied since the 1960s. Plans

for the Integrated Services Digital Network (ISDN) in the 1970s gave direction to the

digital loop development effort, which culminated in the standardized Digital Subscriber

Line (DSL)[108] supporting basic rate ISDN (consisting of two 64 kbps user voice/data

channels and one 16 kbps signaling channel transmitted at a gross rate of 160 kbps,

including overhead) access over qualified two-wire subscriber loops.

Commercial availability of DSL is made possible by the evolution of two

"enabling" technologies, echo cancellation and adaptive equalization, and the parallel

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[107] This is an intentionally simplified description of arrangements that may actually involve pairs or quads of fibers, and more complex recovery mechanisms.

[108] The term "DSL" is narrowly defined as the 160 kbps two-wire technology supporting basic rate ISDN access. It has recently been used more broadly in at least two different ways: in a generic sense to refer to all the technologies derived from the basic DSL "enabling" technologies, and to refer to ADSL in its

development of advanced signal processing techniques that allow the enabling

technologies to be reduced to designs that can be economically contained in VLSI

devices. Digital echo cancellation allows simultaneous two-way transmission of digital

signals over a single two-wire transmission channel, and adaptive equalization circuitry

automatically accommodates specific loop characteristics and transmission impairments

(such as the presence of bridged taps, which cause reflections) and changes in loop

electrical parameters caused, for example, by temperature variations.

The refinement of both these techniques, allowing them to function at rates

considerably higher than the 160 kbps DSL line rate, along with the development of

multilevel line codes[109] well-suited to transmission over existing loops, led to the

commercial development of ADSL, HDSL (High-bit-rate Digital Subscriber Line) and

several other related digital loop transmission techniques. These new loop technologies

allow unidirectional transmission at multi-megabit rates and bidirectional transmission of

at least several hundred kilobits per second up to the DS-1 rate (and higher, under certain

restrictions) over one- and two-pair loops meeting certain requirements. These

techniques are generally known as "xDSL" technologies, as they are all derived from the

original DSL techniques developed for basic rate ISDN.

The following sections contain a review of the various DSL-derived technologies

and their capabilities (along with corresponding loop restrictions), a discussion of

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several variations. We use the term "xDSL" as the generic reference to all such technologies and reserve
the term "DSL" for the 160 kbps basic rate ISDN loop to avoid ambiguity.

[109] A multilevel code defines symbols that represent more than a single binary digit. A simple two-level
line code transmits a symbol that can represent only a logical 0 or logical 1, in other words, a single bit. A
four-level code consists of symbols that can assume any of four states and thus can represent two bits. In

implementation concerns (which may be translated as potential bases for ILEC

roadblocks to xDSL interconnection), and descriptions of interconnection arrangements.

There is also a short glossary for anyone unfamiliar with some of the technical terms in

the paper.

2. Overview of xDSL technologies and loop requirements
   Below is a list of the xDSL family of technologies:

DSL – digital subscriber line

Bidirectional 160 kbps (including overhead bandwidth for framing and synchronization)

over a single pair; supports basic-rate IDSN transmission of two 64 kbps B channels and

one 16 kbps D channel; operates over non-loaded loops with lengths up to 18000 ft.

(Several companies offer range extension devices for DSL signals that allow operation

over loops longer than 30000 ft).

HDSL – high-bit-rate DSL

Bidirectional DS-1 transmission over two pairs; requires no engineering or binder group

separation; operates over CSA loops (up to 12000 ft with 24-gauge cable; non-loaded;

limited bridged tap total distance and single-tap maximum length); each pair carries

bidirectional transmission at one-half the DS-1 rate (actually 784 kbps); regenerators

available from several manufacturers extend operating range to 30000 ft and beyond.

ADSL – asymmetric DSL

Unidirectional (downstream – central office to subscriber) high-bit-rate (1.5 Mbps to 8

Mbps) transmission, plus separate bidirectional digital signals (16 kbps to about 800

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multilevel codes, the transmitted baud rate (the number of symbols transmitted per second) is less than the
end-to-end bit rate. Such line codes generally make better use of limited spectrum.

kbps), with both sets of digital signals frequency-multiplexed onto non-loaded loops up to 18000 ft in length; limited bridged tap total distance and maximum length); analog voice signal transmitted independently of ADSL signals; maximum data rates vary with total copper distance.

SDSL – symmetric DSL

Single-pair version of HDSL; bidirectional high-bit-rate transmission (160 kbps – DS-1, but typically 768 kbps) over CSA loops (but possibly 18000 ft at low rates); non-loaded loops required with limited total bridged tap distance and single-tap maximum length).

RADSL – rate-adaptive DSL

RADSL, as its name suggests, uses terminal equipment that adapts its maximum transmission rates to individual loop conditions, thus allowing service providers to offer ADSL-based services to users on substandard loops, including loops whose lengths exceed the nominal ADSL maximum of 18,000 feet.

VDSL – very high-bit-rate DSL

VDSL is also an asymmetric technique that offers downstream bit rates of possibly several tens of megabits per second. It achieves these rates over distances very much shorter than those of ADSL – at 4500 ft, for example, the maximum rate may be around 13 Mbps, and at 1000 ft or less, the rate can be as high as 52 Mbps, the STS-1 rate (corresponding to the OC-1 rate in SONET fiber networks). VDSL clearly applies to fiber-to-the-curb networks where the final copper run to customer locations is very short.

3.   Interconnection architectures and implementation concerns

The remainder of this discussion addresses ADSL specifically, because of its potential for delivering relatively high-bit-rate services to end users simultaneously with

conventional narrowband analog voiceband services. ADSL may be thought of as existing on a "virtual" loop circuit independently of any conventional switched analog voice signal using the same physical pair. This section contains discussions of specific interconnection concerns and describes potential roadblocks to interconnection that may be constructed by ILECs.

"Splitters"

ADSL (and, as appropriate, SDSL) signals coexist on two-wire loops with analog voiceband signals. As was noted earlier, ADSL consists of a relatively high-bit-rate downstream signal and bidirectional signals of moderate data rate. These signals are frequency-multiplexed, with the analog voiceband signal occupying the lowest frequency range in the spectrum. Separation of these signals is technically straightforward: The voiceband signal is separated from the ADSL signals using passive filters. A DSLAM then separates the ADSL components after the voice signal has been removed; the DSLAM and splitter normally (but not necessarily) are separate devices.

The filtering in conventional ADSL splitters contains both "low-pass" and "high-pass" filters to separate the voiceband and ADSL signals and to isolate the ADSL signals from interference generated by supervision signals (*e.g.*, current pulses resulting from on- and off-hook switching and, now somewhat rarely, dial pulses) associated with the analog voice service. The splitter is combined with the NID, so that the ADSL signal is separated before the inside wiring is encountered. This fact carries with it both good news and bad news. The good news is that splitting at the NID allows the ADSL signals

to avoid the inside wiring, which is electrically messy for digital signals.[110] The bad news is that someone from the ILEC (or, if the NID is unbundled, a competitive service provider) has to drive to the customer location to install a new NID containing the splitter.

There is a modified form of ADSL called "splitterless" ADSL, or, sometimes, "G.lite" (whose name derives from the T1E1.4[111] internal nomenclature for new standards projects). Here, the customer premises device (the DSLAM, or ADSL modem) contains the splitting function. Because the customer buys and installs the ADSL modem, there is no service provider activity required at the customer's location. (The provider still must install corresponding devices in the central office). This arrangement, however, can lead to degraded performance for at least two reasons: The ADSL signals now are exposed to the premises wiring, and the low-pass filter is absent from the modem, thus reducing the electrical isolation between the analog voice signal and the ADSL receivers.

Loop architecture

The simplest case is the all-copper loop, as shown in Figure A1. This is the case addressed by the original ADSL proposal. One might consider the ADSL signals as being carried by a "virtual" loop independently of the POTS signal on the same physical structure.

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[110] Wiring and instrument impedances are poorly controlled, and there are often many unterminated RJ-11 jacks whose connections can appear as bridged taps in the premises wiring, depending on the wiring arrangement. Although the tap lengths are fairly short at ADSL symbol rates, their effects must be considered. Even if there are telephones connected to all these jacks, telephone electrical characteristics vary widely at ADSL frequencies and can impair ADSL signal reception and generation of upstream signals.
[111] T1E1.4 is the standards working group responsible for developing standards and technical papers concerned with systems and interfaces including xDSL.

ADSL carried on an all-copper loop requires a DSLAM at the central office end of the loop and a corresponding ADSL modem, furnished by the customer, at the customer's premises. The feeder pair terminates at the MDF. There must be a splitter at this end of the loop, and it may be located in the MDF, in a separate shelf on the switch side of the MDF, or with the DSLAM itself. If the splitter is not located at the MDF, the voiceband signal at the output side of the splitter must connect back through the MDF to its ultimate connection, usually an line port in the end office switch.

Using ADSL in conjunction with digital loop carrier (DLC) systems is somewhat more complicated than the all-copper case. It doesn't matter whether integrated or universal DLC is in place, as well be seen in the following – the same difficulties arise for either type.

The problem arises from the vastly increased bandwidth made available to each subscriber. In a conventional DLC system, integrated or universal, a single subscriber POTS line requires at most[112] a single (two-way) DS-0 signal on the feeder facility connecting the remote terminal, or feeder-distribution interface (FDI),[113] with the central office.[114] With ADSL, the bandwidth required per subscriber typically increases by at least an order of magnitude, and the problem arises of how to carry the wideband ADSL signals over the feeder connection to the central office.

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[112] In the case of GR-303 DLC using concentration, there will be fewer DS0s on the feeder than there are assigned subscriber lines, because feeder capacity is assigned dynamically.

[113] This document uses the term "feeder-distribution interface", or FDI, to refer to the remote terminal in a DLC system and to a serving area interface in an all-copper loop network. When the FDI is a remote terminal, all associated functions, including optical and electrical cross connects, are assumed to be include in the FDI.

[114] The term "central office" is used to be consistent with FCC usage; in this sense, "central office" is synonymous with "wire center."

Although there are exceptions, many existing DLC systems generally cannot accommodate the extra bandwidth required by ADSL internally. One approach to providing ADSL in such cases is to separate the ADSL data signals from the voiceband signals externally to the DLC RT and then route the data signals through a multiplexer that is an adjunct to the RT. Figure A2 shows an arrangement using a SONET feeder connection with an adjunct ADM/terminal multiplexer that combines the multiplexed ADSL signals with the DLC signals on a common cable.[115] If the DLC RT allows an integrated ADSL interface, the DSLAM and SONET multiplexing functions will be handled by the RT, with the DSLAM function typically being a plug-in card. In both cases, the feeder bandwidth must be greatly increased to allow sufficient capacity for the ADSL signals. The typical GR303 system uses an OC-3 feeder transmission rate; for ADSL applications over common feeder facilities, and with significant ADSL penetration in the group of subscribers served by a DLC, this may need to increase to at least one, and possibly several, OC-48s or higher rates.

The separate multiplexed voice and ADSL signals are separated in the central office, the voice signals being routed to the integrated DLC interface in the end office switch and the ADSL signals to their destinations, either ILEC-owned equipment or CLEC collocation cages.

If the DLC system cannot accept ADSL signals, there must be arrangements for locating, housing (including necessary cross connections), and powering the adjunct
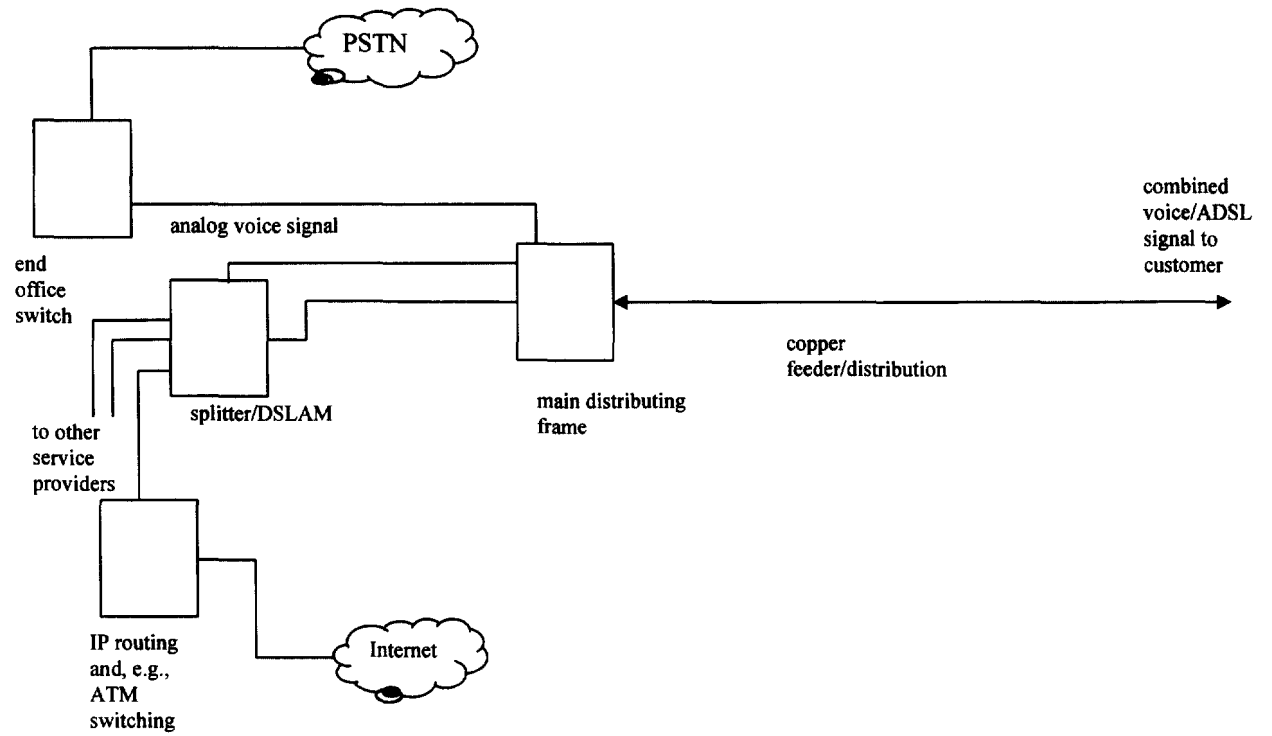
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[115] This is one technically valid approach. It is also possible to carry the ADSL data signals on the same fiber that carries the narrowband voice signals to and from the FDI using some form of wavelength-division multiplexing (WDM).
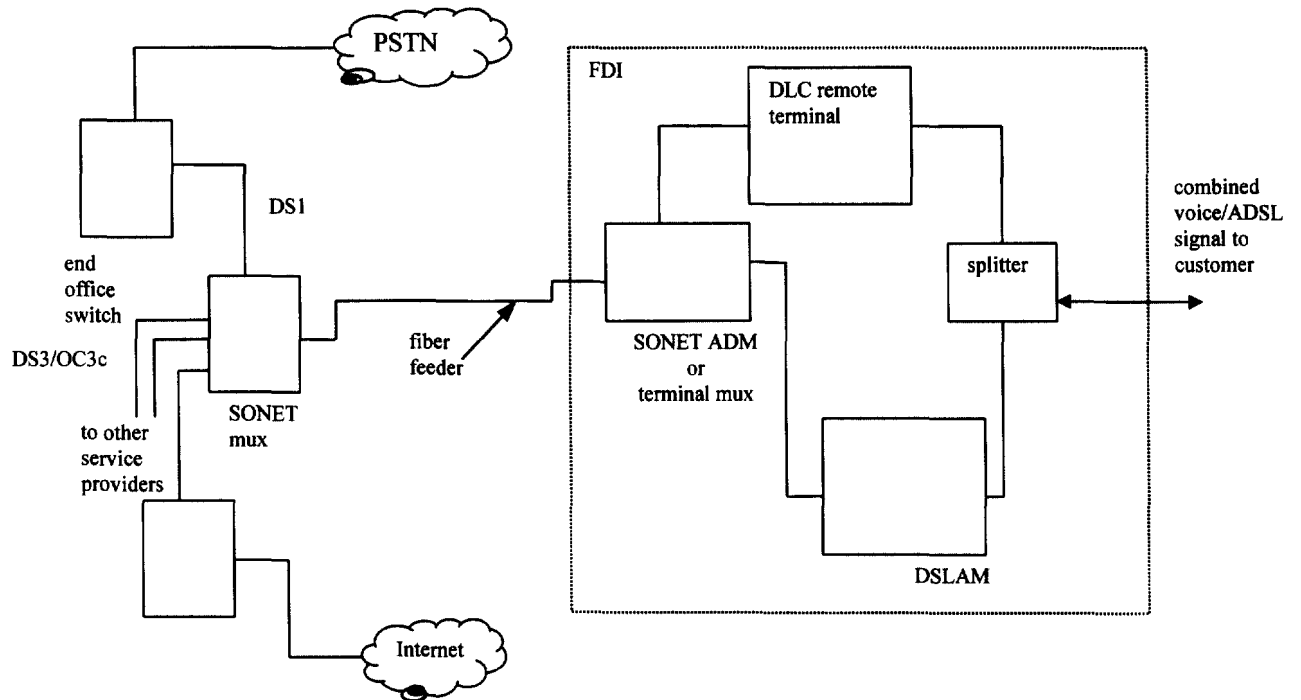
multiplexing equipment, including DSLAM and fiber multiplexer, adjacent to the FDI.

This problem exists equally for the ILEC or a potential UNE user.

Figure A1 ADSL and copper loops

PSTN

combined
voice/ADSL
signal to
customer

analog voice signal

end
office
switch

splitter/DSLAM

to other
service
providers

main distributing
frame

copper
feeder/distribution

IP routing
and, e.g.,
ATM
switching

Internet

Figure A2 ADSL and DLC

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Statement of Qualifications

HAI Consulting, Inc. (formerly Hatfield Associates, Inc.) is an interdisciplinary consulting and research firm serving a wide range of clients with stakes in the telecommunications field. Hatfield Associates was founded in February, 1982. With the departure of Dale Hatfield to the FCC in 1997, the remaining associates formed HAI Consulting, Inc. HAI and Hatfield Associates have provided consulting and educational services in nearly all aspects of the present and future telecommunications infrastructure, including local exchange networks, cable television systems, competitive access networks, land mobile and personal communications, long haul terrestrial and satellite communications, data communications, and customer premises equipment.

The firm has substantive experience in international telecommunication matters. Consulting and educational services are performed for private and public sector clients in Australia, Canada, Mexico, Chile, New Zealand and several countries in Central and Eastern Europe. Principals of the firm include consultants with graduate degrees and decades of senior level experience in engineering, economics, business, and policy/regulation. HAI's services include, among others, regulatory filings and policy studies, engineering studies, expert testimony, market research, economic studies and cost modeling, "due diligence" support, business planning, education and system development.

Examples of recent consulting assignments include:

- Estimating the investments and expenses associated with the provision of local exchange and exchange access and interconnection services;

- Analyzing the potential for competitive entry into the local exchange telecommunications business, presented in papers entitled "The Enduring Local Bottleneck: Monopoly Power and the Local Exchange Carriers" and "The Enduring Local Bottleneck II";

- Testifying in state proceedings on various aspects of competitive entry into local exchange and exchange access services, and on state mechanisms to fund universal service;

- Assessing the technological and economic merits of various telephone companies' plans for offering video dialtone services;

- Modeling the cost of telephone service in Mexico;

- Testifying and filing written testimony in proceedings before the Canadian Radio-telephone and Telecommunications Commission on local telephone competition, interconnection, collocation and number portability;

- Representing clients in U.S. state commission-sponsored negotiations to resolve local interconnection and number portability issues

- Developing a vision statement dealing with the future of cable television networks in providing telecommunications and enhanced video services;

- Authoring the "Telecommunications Technology" and "Utility Applications of Telecommunications" chapters, describing utility opportunities in telecommunications, of a major telecommunications report for the Electric Power Research Institute;

- Analyzing telecommunications opportunities, costs, and modes of entry for several major electric utilities, leading in one case to a decision by the utility to deploy a backbone fiber optics network and partner with other entities in the provision of Personal Communications Services;

- Developing material on telecommunications technology for inclusion in a report on international telecommunications prepared by the Office of Technology Assessment of the U.S. Congress;

- Analyzing trends in telecommunications architectures and technologies for a major computer company;

- Providing tactical advice and computer network support for a client bidding in the FCC auction of 900 MHz Specialized Mobile Radio licenses;

- Assessing opportunities for the branches of the U.S. Military to consolidate their use of wireless communications;

- Providing analyses for an investment firm contemplating a major investment in a paging company; and

- Providing telecommunications education to countries in Central and Eastern Europe.

Richard A. Chandler
Senior Vice President

Richard A. Chandler is a senior vice president with HAI Consulting, Inc., where he performs a range of consulting services for clients, including evaluation of various communication technologies to address specific user requirements, review of large corporate network structures and operations, as well as the evaluation of the suitability of new products for particular markets. Among other assignments as a consultant, he has developed the technical plan for a proposed wireless-based telecommunications system to provide basic internal telephone service as well as international connectivity to the populace of a developing nation. He has worked with a Korean international carrier in the development of the technical and operating plan for a proposed Korean PCS network. Other contracts have involved the development of regional and nationwide architectures for mobile data networks and evaluation of voice compression and automated conferencing systems to support both internal and external investment decisions. He has worked extensively in the wireless communication area, studying Personal Communications Network architectural issues, including radio segment structures, backhaul networks, and interconnection issues for several clients. Most recently, Mr. Chandler has developed sophisticated telecommunications network models for use in determining the costs of telephone service, including local and toll; he has been the principal developer of the Hatfield and HAI Models commissioned by MCI Telecommunications Corporation and AT&T Corp. for use at the state and national levels in supporting interconnection and universal service filings. He has also written numerous affidavits and declarations dealing with various telecommunications technologies in several regulatory and court proceedings.

Before joining Hatfield Associates (now HAI Consulting, Inc.) in 1986, Mr. Chandler joined Skylink Corporation as Vice President - Network Engineering. While at Skylink, Mr. Chandler developed the ground system control and switching architecture and user terminal requirements for the proposed Skylink network. He developed a distributed control structure which allowed for the decentralization of system intelligence, enabling the simultaneous operation of multiple independent subnetworks. He also developed a packet switching mechanism for the network which enables hundreds of interactive users to share a single radio channel for data transmission. He worked jointly with mobile radio and satellite earth station manufacturers to develop preliminary ground terminal and user terminal functional requirements and technical specifications.

Mr. Chandler joined the AT&T marketing organization in 1981, where he initially was a product manager for data switching and adjunct processor enhancements for existing PBX products. In this capacity, he was responsible for coordinating design, development, and manufacturing efforts, developing business case inputs for product pricing, and coordinating training and advertising for the new products. In another assignment within this organization, he developed product strategies for advanced data switching technologies, including adjunct packet switches for customer data. He also headed a group furnishing technical support regarding product architecture and features to the AT&T field sales force and providing customer requirements to the development and product management organizations.

In 1977, Mr. Chandler joined Bell Telephone Laboratories, where he participated in exploratory studies of new PBX systems for AT&T. These investigations included the review of various switching system architectures and control structures for next-generation private branch exchanges. He designed and developed segments of a laboratory model of a new PBX and coordinated designs and interfaces for the production version of the new machine. He also studied design approaches and circuit modifications to enhance the reliability of new switching systems. In another significant assignment, he worked on packet switching techniques to be applied to a multi-processor control structure, and he participated in the development of specific packet switch designs to be applied as an adjunct to the circuit-switched network fabric for the purpose of switching user terminal-to-host and host-to-host data traffic.

From 1972 to 1977, Mr. Chandler was an electronic engineer with the Institute for Telecommunication Sciences, a telecommunications research organization within the U.S. Department of Commerce. While at ITS, he performed microwave propagation studies for atmospheric paths in the 60 GHz region, and he developed experiments for studies of space-to-earth paths at 20 GHz and 30 GHz. He also designed experiments and associated instrumentation for availability studies of short atmospheric optical paths in the near infrared. In addition, he participated in and co-authored an extensive review of existing and future cable television technology. He managed a project for the U. S. Department of Transportation for the evaluation of the applicability of tracking radar techniques to vehicular braking systems, and he managed a consulting contract with the National Oceanic and Atmospheric Administration for the technical evaluation of various commercial microwave positioning systems used in hydrographic surveying.

Mr. Chandler received B.S. and M.S. degrees in electrical engineering from the University of Missouri and an M.B.A. from the University of Denver. He pursued additional graduate work in electrical engineering at the University of Colorado. He serves as an adjunct faculty member at the University of Colorado and the University of Denver and teaches graduate-level courses in telecommunications technology, including wireless and cellular communications and digital switching and transmission.

A. Daniel Kelley
Senior Vice President

Dr. Kelley specializes in economics and public policy analysis for long distance, competitive local exchange, mobile communications, and cable television clients. Since joining HAI in 1990, he has been involved in antitrust and regulatory investigations that address cost allocation, cross-subsidy, and dominant firm pricing. He has authored or co-authored papers submitted in the Federal Communications Commission's Video Dialtone, Advanced Intelligent Network, and Cable Rate Regulation proceedings. In addition, he has advised clients on the Computer III, Open Network Architecture, Access Transport Competition, Price Cap, and Local Interconnection proceedings. Dr. Kelley has provided expert testimony on competition, cross-subsidy, interconnection and universal service issues before the Federal Communications Commission and the California, Colorado, Connecticut, Florida, Georgia, Hawaii, Maryland, Massachusetts, Michigan, Oregon, New Jersey, and New York Public Utility Commissions.

His international experience includes advising the governments of Chile and Hungary on competition and privatization and advising a private U.S. corporations on competition and interconnection issues in Mexico and New Zealand. Dr. Kelley has participated in State Department sponsored seminars and University level instructional courses in the Czech Republic, Hungary, Poland, the Slovak Republic and Slovenia.

Prior to joining HAI in 1990, Dr. Kelley was Director of Regulatory Policy at MCI Communications Corporation. At MCI he was responsible for developing and implementing public policy positions on the entire spectrum of regulatory and legislative issues facing the company. Matters in which he was involved included the MFJ Triennial Review, Congressional Hearings on lifting the Bell Operating Company Line of Business restrictions, Tariff 12, Dominant Carrier Regulation, Local Exchange Carrier Price Caps, and Open Network Architecture. He also managed an interdisciplinary group of economists, engineers and lawyers engaged in analyzing AT&T and local telephone company tariffs.

Dr. Kelley was Senior Economist and Project Manager with ICF, Inc., a Washington, D.C. public policy consulting firm, from 1982-1984. His telecommunications and antitrust projects included analysis of the competitive effects of AT&T's long distance rate structures, forecasting long distance telephone rates, analysis of the FCC's Financial Interest and Syndication Rules, and competitive analysis of mergers, acquisitions and business practices in a variety of industries.

From January 1978 to September 1982, Dr. Kelley was with the Federal Communications Commission. At the FCC he served as Special Assistant to Chairman Charles D. Ferris. As Special Assistant, he advised the Chairman on proposed regulatory changes in the broadcasting, cable television and telephone industries, analyzed legislation and drafted Congressional testimony, and coordinated Bureau and Office efforts on major common carrier matters such as the Second Computer Inquiry and the Competitive Carrier Rulemaking. He also held Senior Economist positions in the Office of Plans and Policy and the Common Carrier Bureau.

Dr. Kelley was a staff economist with the Antitrust Division, U.S. Department of Justice, from September 1972 to January 1978. At the Justice Department he analyzed competitive effects of mergers and business practices in the cable television, broadcasting, motion picture, newspaper and telephone industries. As a member of the economic staff of U.S. v. AT&T, he was responsible for analyzing proposals for restructuring of the Bell System.

Dr. Kelley received a Ph.D. in Economics from the University of Oregon in 1976, with fields of specialization in Industrial Organization, Public Finance and Monetary Theory. He also holds an M.A. in Economics from the University of Oregon and a B.A. in Economics from the University of Colorado. He has published numerous articles on telecommunications economics and public policy and regularly participates as a speaker at academic and industry conferences.

Robert A. Mercer
President

Dr. Mercer provides strategic planning and education related to public and private telecommunications infrastructures, with a particular emphasis on local exchange competition, broadband integrated networks, intelligent networks, and private enterprise networking. Examples of current work include the analysis of competitive alternatives for the provision of local exchange services, evaluating the cost of local exchange service provided by incumbent telephone companies and other competitive entities, and advising a client on the means for evaluating the performance of its network services integrator.

Dr. Mercer conducts telecommunications policy analyses, with particular current emphasis on the interconnection, unbundling, resale, and universal service aspects of the 1996 telecommunications legislation, and past involvement in FCC and state proceedings on Open Network Architecture (ONA) and Video Dial Tone (VDT). He is a co-author of the well-known "Hatfield Report" and "Hatfield II Report" on the ONA concept, and of a report titled "The Enduring Local Bottleneck" which deals with the ability of alternative providers to enter the local exchange telecommunications business. Has also testified before state regulatory bodies in proceedings pertaining to the cost of local exchange service and on the conditions necessary for local exchange competition to flourish.

Dr. Mercer has served as an adjunct faculty member in the Interdisciplinary Telecommunications Program (ITP) at the University of Colorado, where he has taught a course in advanced data communications and computer networking. He has also taught courses on telecommunications infrastructure directions, multi-protocol networking, TCP/IP, Asynchronous Transfer Mode (ATM), Open Systems Interconnection (OSI), network management, and telecommunications standards, as well as presenting numerous public seminars and talks on a variety of telecommunications topics. He directs and participates on Master's thesis committees in the ITP, and also participates in effort to define and coordinate the program's curriculum, particularly as it pertains to data communications.

<u>Department Head of Datakit Systems Engineering</u>, AT&T Bell Laboratories, 1986-1987

Directed systems engineering of the Datakit product, a virtual circuit switching data communications product of AT&T Technologies. Participated extensively in AT&T planning of its data communications architecture, and the products and services resulting from that architecture.

<u>Senior Executive</u>, BDM Corporation, 1985-1986

Planned data communications networks for various defense agencies. Served as a consultant to several clients on data protocol issues. Developed market projections for secure LANs.

<u>Assistant Vice President of Network Compatibility Planning</u>, Bell Communications Research (Bellcore), 1983-1985

Directed Bellcore support of the Bell Operating Companies (BOCs) in meeting the technical Equal Access requirements of the Modified Final Judgement. Conducted technical fora with the Inter-exchange Carriers and other carriers on behalf of the BOCs. Managed the North American Numbering Plan. Directed Bellcore's involvement in standards-making efforts, and played a key role in the formation of a new U. S. standards committee, Committee T1. Managed the "technical regulatory" work at Bellcore, which analyzed technical aspects of various FCC proceedings, including the ISDN Inquiry, the consideration of how the Computer II rules applied to the divested BOCs, and Computer III. With respect to the latter, was heavily involved in the work on the Comparably Efficient Interconnection concept, which later led to the Open Network Architecture (ONA) concept.

<u>Director of Network Architecture Planning</u>, Bell Laboratories, 1981-1983

Managed early Bell System planning for the Integrated Services Digital Network (ISDN). Provided project management to two key data network planning and implementation activities. Managed Bell Laboratories involvement in several U. S. and international standardization activities. Participated in planning for the Bell Laboratories reorganization in preparation for the AT&T Divestiture.

<u>Division Manager of Network Services Standards</u>, AT&T, 1979-1981
Managed the effort to describe the interface and performance characteristics of the Bell System network, particularly as necessary to meet the terms of the FCC Registration Program. Directed several components of the Bell Systems participation in international telecommunications standards committee CCITT.

<u>Supervisor</u> and <u>Member of Technical Staff</u>, Bell Laboratories, 1973-1979

Analyses of network performance issues and customer perceptions of performance, highlighted by direction of a pioneering study of customer retrial and abandonment behavior during long-distance telephone calls. Planning for operational processes and operations support systems associated with new Bell System services.

Education

<u>B.S., Physics</u> (1964), Carnegie Institute of Technology.
<u>Ph.D., Physics</u> (1969), Johns Hopkins University.

Other Activities and Awards

Former member of the Board of Directors, American National Standards Institute. Member of the Institute of Electrical and Electronic Engineers (IEEE) and Sigma Xi, the scientific research society.